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Reform of the Practical Teaching System for the Measurement and Control Technology and Instrumentation Program Oriented toward Engineering Practice Competence

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Abstract: To address the problems in the practical teaching of the Measurement and Control Technology and Instrumentation program, including insufficient articulation among courses, inadequate transition from verification experiments to comprehensive design, limited integration of engineering contexts, insufficient depth of students' autonomous practice, and an overemphasis on outcome-based assessment, this study, guided by outcome-based education and engineering education accreditation requirements, takes the development of engineering practice competence as the main thread and constructs a four-level progressive and project-integrated practical teaching system consisting of "Basic Training-Professional Integration-Engineering Application-Innovation Enhancement". Students' practical competence is divided into four progressive levels: basic practical competence, professional comprehensive competence, engineering system competence, and innovative practice competence. Project-driven tasks are used to connect course experiments, course design projects, comprehensive professional practice, enterprise internships, and graduation projects, while a multidimensional assessment and continuous improvement mechanism combining process evidence with outcome assessment is established. The proposed system emphasizes the coordinated progression of task complexity and student autonomy and provides an operable teaching framework for promoting the transformation of practical teaching from isolated skill training to the cultivation of system-level engineering competence.

Keywords: Measurement and Control Technology and Instrumentation; Practical Teaching; Engineering Practice Competence; Project-Driven Learning; Continuous Improvement.

1. Introduction

The Measurement and Control Technology and Instrumentation program integrates knowledge from sensing and detection, electronics, signal processing, automatic control, computers, and precision instruments. It is characterized by its interdisciplinary nature, strong emphasis on engineering practice, and rapid technological advancements. With the development of technologies such as smart sensing, the Industrial Internet, digital instruments, and smart manufacturing, measurement and control systems are increasingly characterized by the convergence of hardware and software, networking, and intelligence. This places higher demands on students' ability to integrate cross-disciplinary knowledge and solve complex engineering problems. Students must not only understand fundamental theories and typical methods but also experience the entire process-from requirements analysis and scheme design to system implementation, debugging and testing, performance assessment, and engineering communication.

In recent years, engineering education reform has consistently emphasized the cultivation of practical and innovative abilities. The Excellent Engineer Education and Training Program 2.0 issued by the Ministry of Education and other relevant authorities places greater emphasis on engineering practice, innovation and entrepreneurship education, as well as teachers' engineering practice competence [1]. The "Engineering Education Accreditation Standards (2024 Edition)" released by the China Engineering Education Accreditation Association also emphasize student-centeredness, outcome-based education, and continuous improvement, and require programs to develop practical teaching systems that are consistent with their educational objectives and graduation requirements [2]. These requirements show that practical instruction is an important part of developing students' engineering competencies rather than simply a supplement to theoretical courses.

Over the past two years, research on practical teaching reform in instrumentation, measurement and control, and related engineering disciplines, especially under the "New Engineering" initiative, has gradually moved beyond the improvement of individual course experiments toward competency-based, project-driven, and more systematic practical training. To address the problem of limited practical depth in the traditional "Sensors and Detection Technology" course, Wei et al. developed a progressive training model consisting of "virtual simulation-hardware-in-the-loop debugging-system integration verification" and revised the course assessment system from three aspects: knowledge, competence, and professional qualities [3]. Jin et al. carried out teaching reform in the "Modern Instrument Design" course of the Measurement and Control Technology and Instrumentation program from the perspectives of New Engineering and industry-education integration. By updating the course content and increasing interactive and practical teaching activities, they sought to strengthen students' engineering practice and innovation capabilities [4]. Li et al., focusing on the "Signals and Systems" course for the Measurement and Control Technology and Instrumentation major, integrated professional engineering problems into the

course content, blended learning, and formative assessment processes, emphasizing the development of students' problem-analysis, problem-solving, and teamwork skills [5]. In engineering practice instruction, Du et al. used a flywheel energy storage system as the basis for a project that combined design modeling, machining, manufacturing, assembly, and debugging, with the aim of developing students' engineering practice, innovation, and teamwork skills [6]. Shi Yong and colleagues used a virtual 3D printer project in mechatronics teaching, allowing students to apply knowledge from mechanical design, microcontroller control, and computer programming within a single project task [7]. Zhang et al. examined a teaching model that integrates graduation internships with graduation projects from the perspective of engineering education accreditation [8]. Kong et al. explored changes in the teaching objectives, content, and assessment methods of engineering drawing courses based on the OBE philosophy [9]. Zhao et al. focused on the "Sensing and Testing Technology" course and carried out reforms in teaching content, comprehensive innovation experiments, and diversified assessment methods [10].Overall, existing research has gradually shifted from the optimization of individual course instruction toward the cultivation of engineering practice competence; however, there remains room for further integration and refinement regarding the vertical alignment among different practical courses, the progressive development of student competencies, and the assessment of projects throughout their entire lifecycle.

Therefore, rather than focusing primarily on increasing the number of experiments, this paper takes the process of developing engineering practice competence as its central theme. It integrates the design of practical objectives, course and project organization, faculty guidance methods, assessment and evaluation, and mechanisms for continuous improvement, thereby forming a reform approach characterized by "tiered competency development, project-based integration, process-based assessment, and continuous improvement."

2. Major Problems in Practical Teaching for the Measurement and Control Program

Based on relevant research and the requirements of engineering education accreditation regarding practical skills, the resolution of complex engineering problems, and continuous improvement, there are still some common challenges in the practical instruction of measurement and control and related engineering disciplines, which are primarily reflected in the following areas.

2.1. Numerous Practical Teaching Components but Insufficient Vertical Articulation

The Measurement and Control major typically includes practical components such as electrical and electronic experiments, sensor experiments, measurement and control circuit experiments, microcontroller or embedded-system experiments, automatic control experiments, course design projects, comprehensive professional practice, introductory internships, production internships, and graduation projects. In regard to the amount, the practical training contents are abundant; however, most courses carry out experiments separately according to their own special knowledge points, which leads to a deficiency in the clear progression of skills from one course to another. Students might finish the sensor calibration in one course, the amplification and filtering in another, and then study the data acquisition and programming in subsequent courses, but they may not necessarily gain a thorough systematic knowledge of the procedure from "measured object-sensor-signal conditioning-data acquisition and transmission-data processing-display and control."

2.2. Insufficient Transition from Verification Experiments to Comprehensive Design Tasks

Verification experiments play a fundamental role in understanding principles, becoming familiar with instruments, and establishing operational standards. However, if fixed equipment, fixed wiring, fixed parameters, and fixed procedures are used over the long term, students will primarily develop the operational ability to "complete tasks according to the manual." Real-world engineering tasks typically do not have a single technical solution; instead, they require comprehensive consideration of constraints such as measurement range, accuracy, dynamic response, environmental adaptability, cost, and system complexity when selecting a solution. If practical instruction lacks a progressive transition from verification-oriented tasks to design-oriented and comprehensive tasks, students may encounter difficulties when they enter the comprehensive course design or graduation project phase-specifically, they may be able to operate individual modules but be unable to develop a complete system solution.

2.3. Insufficient Integration of Engineering Contexts and Constraints

To ensure they can be completed within a limited number of class hours, classroom experiments often involve significant simplifications of the problems. While this helps highlight key concepts, it can easily downplay the engineering context. In the design of actual measurement and control systems, factors such as measurement uncertainty, interference immunity, communication reliability, energy consumption, cost, safety, and maintainability must also be considered. If practical assignments remain limited to "implementing a specific function" over the long term, students will struggle to understand that engineering design is, at its core, a process of trade-offs and optimization under multi-objective constraints.

2.4. Limited Opportunities for Autonomous Practice and Trial and Error

In traditional laboratory instruction, instructors typically provide circuit diagrams, program frameworks, and operating procedures in advance, and students simply follow the steps in order. While this approach ensures that the class stays on schedule, it undermines the process of identifying problems, troubleshooting, and testing hypotheses. Wiring errors, inappropriate parameter selection, sampling anomalies, communication failures, and program timing issues in measurement and control systems are, in themselves, crucial components of engineering skills training. If instructors provide the answers too early, students will struggle to develop the ability to debug and troubleshoot problems independently.

2.5. Assessment Overly Focuses on Final Outcomes

Some practical courses are primarily graded based on lab reports, the functionality of physical prototypes, or final demonstrations, making it difficult to fully reflect the scheme justification, task allocation, debugging records, problem-solving, and individual contributions. Team projects, in particular, are prone to situations where "the final products are identical, making it difficult to distinguish differences in individual abilities." Therefore, it is necessary to shift the assessment of practical work from a one-time assessment of outcomes to one that equally emphasizes process evidence, engineering performance, and the quality of the final product.

3. Design of Engineering Practice Competence Development Objectives

Outcome-based education emphasizes designing curricula and instructional activities in a backward manner, starting from the competencies students are ultimately expected to acquire [9]. Based on the knowledge structure of the measurement and control discipline and the characteristics of engineering tasks, this paper categorizes practical competencies into four levels: basic practical competence, professional comprehensive competence, engineering system competence, and innovative practice competence. These four categories of competencies progress sequentially from low to high, corresponding not only to students' different stages of learning but also to the process of increasing complexity and autonomy in practical tasks. The progressive relationship among these four categories of competencies is illustrated in Figure 1.

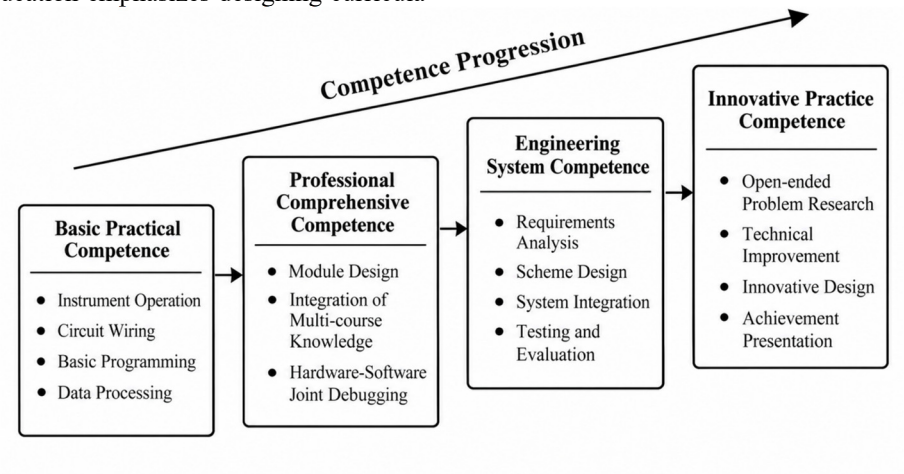


Fig 1. Framework for Practical Competence Development in the Measurement and Control Technology and Instrumentation Program

Basic practical competence primarily include the use of common instruments, circuit assembly, basic programming, experimental data processing, laboratory safety, and technical documentation; these form the foundation for subsequent specialized practical training. Comprehensive professional skills emphasize the modular integration of knowledge in sensing, signal conditioning, data acquisition, processing, and control to address the challenge of "how to synergistically apply knowledge from multiple courses." Engineering system competence requires students to address relatively comprehensive tasks by conducting requirements analysis, comparing solutions, integrating systems, and conducting performance testing and optimization; innovative practice competence emphasizes information retrieval, making technical improvements, and developing innovative solutions for open-ended problems, while being able to validate and articulate these through experimental or project outcomes. The correspondence between each competency level and typical practical teaching components is shown in Table 1.

Table 1. Correspondence between Practical Competence Levels and Typical Teaching Activities

Competency Levels	Main Training Content	Typical Practical Teaching Activities
Basic Practical competence	Instrument Operation, Circuit Connections, Basic Programming, Data Processing, Experimental Standards	Basic experiments, foundational professional experiments
Professional comprehensive competence	Module design, integration of multi-course knowledge, hardware–software joint debugging	Comprehensive experiments, course design projects
Engineering system competence	Requirements analysis, scheme design, system integration, testing and optimization	Comprehensive professional practice, engineering projects, enterprise internships
Innovative practice competence	Independent topic selection, technical improvement, open-ended design, innovative implementation	Open experiments, innovation projects, graduation projects

4. Construction of a "Four-Level Progressive and Project-Integrated" Practical Teaching System

Centered on the aforementioned competency objectives, this study constructs a four-level progressive practical teaching system comprising "Basic Training-Professional Integration-Engineering Application-Innovation Enhancement," with project tasks of varying complexity linking the four levels. The main idea of this method is not to convert all the courses into large scale projects, but to make sure that the practical works at various levels have a continuous progress according to the competency requirements: the lower level projects focus on the basic specifications and module functions; the middle level projects focus on the integration of knowledge from different courses; the upper level projects focus on the system design under complex conditions; and the innovative level projects focus on openness and independence. The general structure is illustrated in Figure 2.

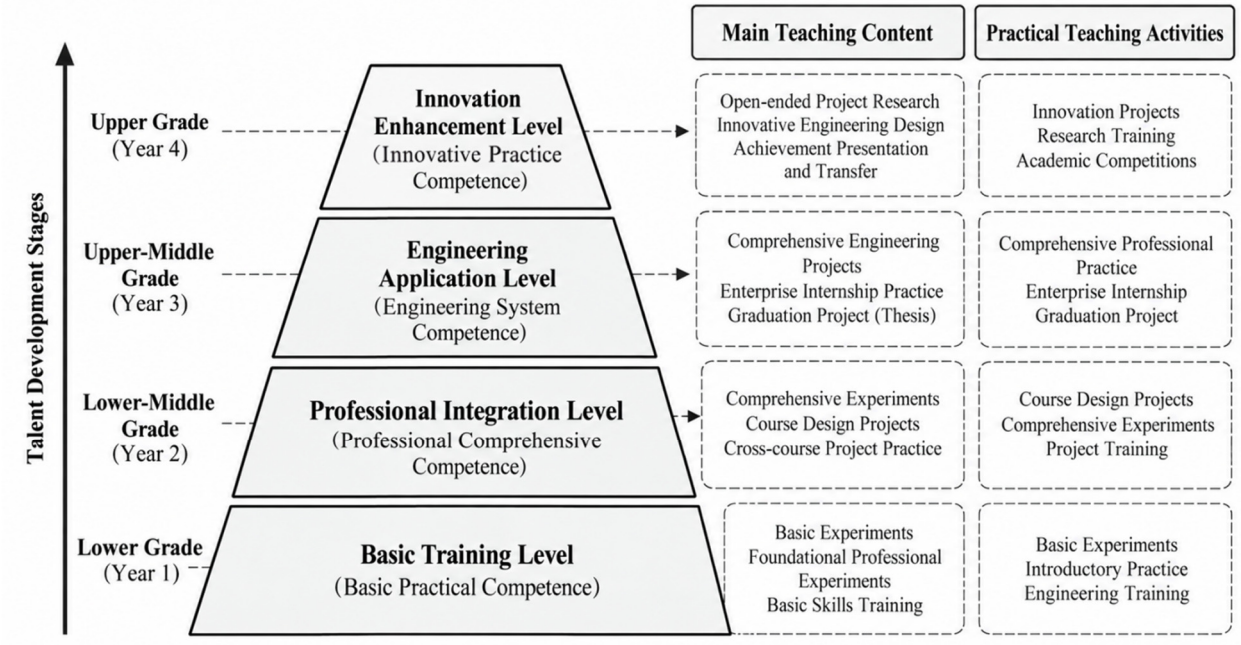


Fig 2. A Practical Teaching Framework Based on "Four-Tiered Progression and Project Integration"

4.1. Basic Training Level: Reinforcing Basic Skills and Engineering Standards

For novice students, the principal practical instructions concentrate on the use of common instruments, circuit construction, elementary programming, signal recognition and data processing. At present, some essential verification experiments can be conducted; however, besides finishing the assigned work like changing parameters, examining errors and clarifying the results, these operations should also be included to enhance the students' capability in recognizing measurements, maintaining standards and understanding data during the learning of fundamental operations. For routine experiments, the evaluation criteria should not only consider the accuracy of the results but also the thoroughness of the experimental records, the rationality of the parameter choices and the exactness of the error analysis.

4.2. Professional Integration Level: Transitioning from Knowledge-Point Verification to Functional Module Design

After entering the specialized study stage, the practical training should mainly concentrate on the design of functional modules instead of checking individual concepts[11]. According to a relatively constant experimental task, the laboratory exercises from various courses can be organized as connected modules. For instance, the sensor course deals with the detection and calibration; the measurement and control circuits course handles the signal conditioning; the embedded systems course manages data acquisition and communication; and the signal processing course is concerned with the data analysis. The courses do not necessarily have to use the same hardware, but they should have a common problem background, technical requirements or data interfaces, so that the students can gradually know how the knowledge from each course connects to the whole system.

4.3. Engineering Application Level: Training the Complete Engineering Process through Comprehensive Projects

Senior-level comprehensive professional practice should focus on training students in the complete process "from requirements to system." Project assignments should not simply require students to "build a certain device" but should instead specify engineering-relevant functional specifications and constraints. Students must complete requirements analysis, compare technical approaches, select key components, integrate hardware and software, and conduct performance testing and optimization, while also preparing design specifications, test records, and presentation materials. Instructors should conduct reviews at key milestones rather than providing a complete solution at the outset of the project.

4.4. Innovation Enhancement Level: Integrating Open-Ended Practice, Research Training, and Graduation Projects

For students with a certain level of system design capability, more open-ended practical tasks can be provided through open-ended experiments, undergraduate innovation training programs, academic competitions, faculty research projects, and real enterprise needs [12]. As the most comprehensive practical component of the undergraduate program, the graduation project should focus on assessing students' ability to independently analyze problems, develop solutions, conduct experimental validation, and evaluate results. When selecting topics, there should be a moderate increase in engineering context and practical constraints, while reducing the number of topics with an excessively low workload or those that merely replicate existing experimental procedures.

5. Organization and Implementation of Project-Driven Teaching

The key to project-based learning lies not in the scale of the project, but in organizing student learning through the project process[13]. Based on students' ability levels, projects can be categorized into Level 1, Level 2, and Level 3: Level 1 projects focus on the application of knowledge within a single course; Level 2 projects support course-based design or interdisciplinary practical projects; and Level 3 projects are geared toward comprehensive professional practice, innovation projects, and graduation projects. The project level being higher means that less steps are fixed by the teacher and more opportunity for independent decisions of the students exists. The three levels of projects make a progressive development from the application of the course knowledge to the comprehensive engineering practice. The detailed implementation procedure is illustrated in Figure 3.

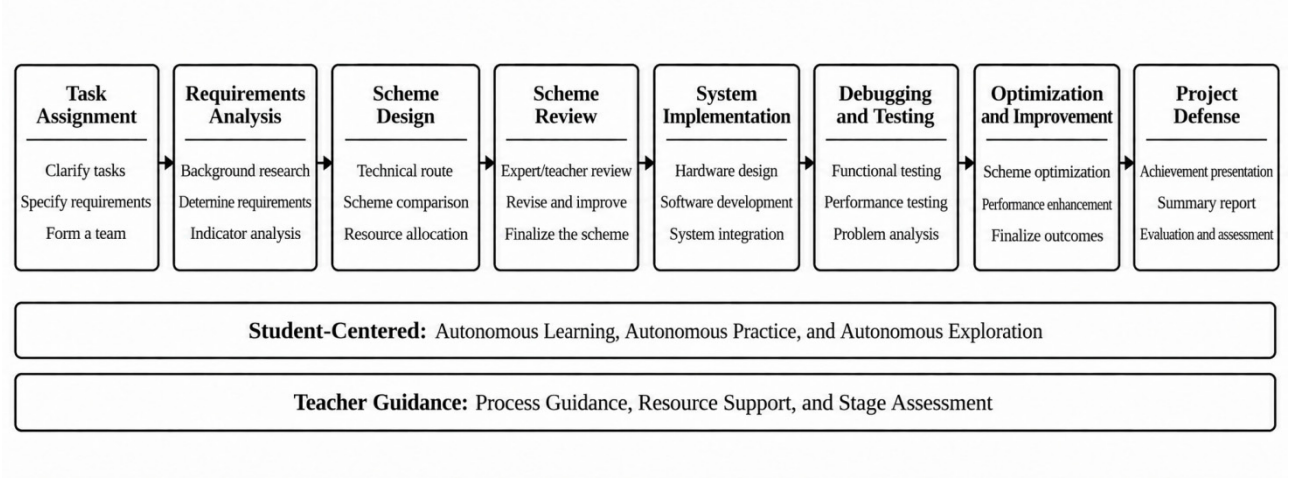


Fig 3. Implementation Process of Project-Driven Practical Teaching

The implementation process can be organized into eight stages: Task Assignment, Requirements Analysis, Scheme Design, Scheme Review, System Implementation, Debugging and Testing, Optimization and Improvement, and Project Defense. In the Task Assignment stage, the project objectives, functional requirements, boundary conditions, and assessment criteria are defined. During Requirements Analysis, students translate the assigned task into measurable technical requirements. In the Scheme Design stage, students develop the technical route, compare possible solutions, and determine the required resources. The Scheme Review stage is used to identify potential problems and improve the proposed scheme through peer discussion and instructor feedback. During System Implementation, students complete hardware construction, software development, and system integration. The Debugging and Testing stage focuses on functional verification, performance testing, and problem analysis. In the Optimization and Improvement stage, students refine the system based on test results and debugging records. Finally, the Project Defense stage evaluates students' understanding of the project, their design decisions, and their ability to explain the technical rationale behind the final solution.

The role of teachers should also change as project difficulty increases. At the foundational level, teachers can continue to provide standardized examples and operational guidance. At the comprehensive level, more heuristic questioning and Scheme Reviews can be introduced. At the engineering and innovation levels, teachers can focus more on task design, resource coordination, process monitoring, and risk management. This arrangement helps avoid excessive teacher direction while still giving students enough support when they work in a more open-ended learning environment.

6. Assessment and Continuous Improvement of Practical Teaching

6.1. Establishing a Multidimensional Assessment System Combining Process and Outcomes

Practical skills develop throughout the learning process, so relying only on the final project or lab report may not provide a complete assessment. For a comprehensive project, assessment can include four parts: scheme design, the practical process, system results, and a final defense. These can be further examined from six competency dimensions: scheme design, practical operations, problem-solving, system integration, teamwork, and engineering communication. scheme design focuses on requirements analysis and technical approaches; the practical process emphasizes debugging records, problem identification, and task progress; system results evaluate functionality and performance; and the final defense assesses engineering communication and understanding of the subject matter. Different courses may adjust the specific weightings of each competency dimension based on their instructional objectives and the characteristics of the project.

Table 2. Assessment indicators and illustrative weights for comprehensive practical projects

Assessment Dimension	Main Assessment Content	Illustrative Weight / %
Scheme design competence	Requirements analysis, technical route, rationality of the scheme	20
Practical operation competence	Instrument use, circuit debugging, program implementation	20
Problem-solving competence	Fault analysis, abnormal-condition handling, improvement and optimization	20
System integration competence	Functional implementation, performance indicators, engineering constraints	20
Teamwork competence	Task allocation, communication and collaboration, individual contribution	10
Engineering communication competence	Technical documentation, presentations and defense, presentation of outcomes	10

Given the differences in instructional objectives, project complexity, and competency requirements across various practical courses, this paper provides only one example of a weighting configuration; the specific weights for each assessment dimension may be adjusted based on course objectives and actual teaching circumstances.

6.2. Emphasizing Individual Contributions and Process Evidence

In addition to evaluating the team's overall results, team projects should also include individual work logs, progress reports, version histories, or debugging checklists. During the final defense, instructors may randomly ask questions about different modules and assess individual contributions based on peer assessments within the group and the instructor's process records, thereby reducing imbalances in team members' contributions. For larger-scale course projects, a standardized template can be used to document the symptoms, hypothesized causes, verification methods, and resolution outcomes for each debugging session, ensuring that the problem-solving process is traceable.

6.3. Establishing a Closed-Loop Mechanism of "Assessment-Analysis-Improvement"

Practical teaching reform should be adjusted continuously on the basis of teaching data and feedback. Relevant information can come from the attainment of course objectives, project assessment results, student surveys, the quality of graduation projects, participation in competitions and innovation training, as well as feedback from internship sites and employers. These data can help identify weaknesses in specific competency dimensions and provide a basis for adjusting project difficulty, course articulation, and teaching methods. On this basis, a closed-loop process of "assessment-analysis-improvement" can be formed, as shown in Figure 4.

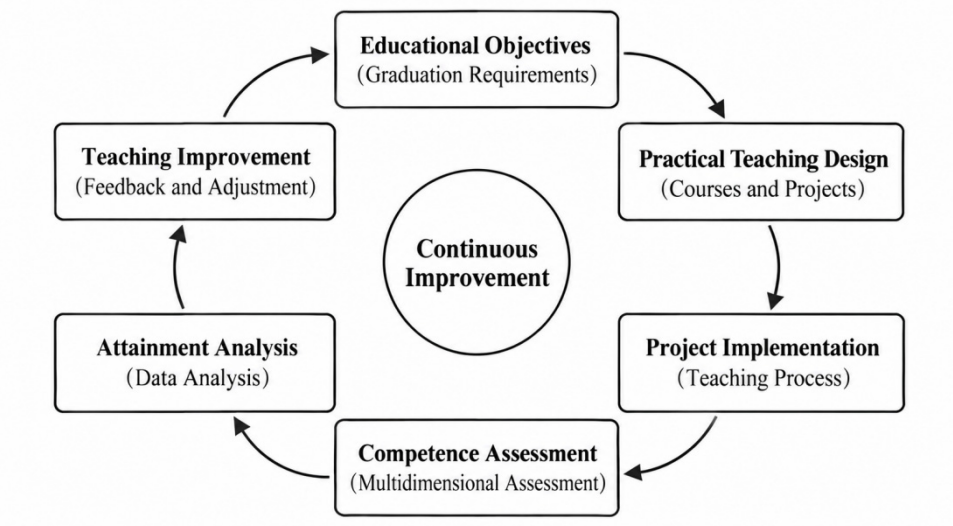


Fig 4. Closed-Loop Assessment and Continuous Improvement of Practical Teaching

For example, when students perform well in basic operations but continue to achieve lower scores in design and system integration, simply adding more experiments may not solve the problem. It is more useful to examine whether the existing tasks are too closed, whether there is enough collaboration across courses, and whether project requirements leave sufficient room for independent decision-making. If a team project achieves good overall results but individual performance varies considerably, more attention can be given to process records and individual defenses. Through the cycle of "educational objectives-practical teaching design-project implementation-competence assessment-attainment analysis-teaching improvement," reform measures can be adjusted gradually on the basis of evidence.

7. Supporting Conditions for Reform Implementation

7.1. Enhancing Teachers' Engineering Practice Competence and Collaborative Teaching

Due to the high requirements of project-based practical education, the instructors should not only be familiar with the course material but also have experiences in system integration, engineering debugging and project management. The engineering-oriented teaching abilities of the faculty can be improved by means of industrial internships, industrial-academic cooperative projects, joint supervision between industries and institutions, and collaborative lesson planning among the teaching teams. For cross-curriculum projects, a coordination system among the course leaders can be set up to reach an agreement on the project interfaces, competency goals and evaluation standards, thus avoiding the separate operations of different courses.

7.2. Improving the Openness and Resource Reuse of Experimental Platforms

The development of practical training systems ought to change from "providing assistance for a particular course" to "promoting the improvement of a certain ability level." At the same time, the utilization efficiency of the open laboratories should be enhanced by permitting the students to apply the same sensing, data acquisition, communication and control modules in various project stages. If the equipment resources are scarce, the opportunities for practical training can be increased by means of collaborative platforms, the combination of virtual and actual environments, rotation work and reservation access.

7.3. Building Dynamically Updated Project and Case Libraries

Technology for measurement and control develops quickly, and the projects which do not change for a long time may lose connection with actual engineering problems. The project repository is divided into four aspects: fundamental, complete, engineering and innovative, and new teaching situations can be produced frequently by referring to industrial examples, faculty investigations, competition assignments and industrial requirements. The emphasis of modification should not be put on changing the hardware frequently, but rather on altering the context of the task, the evaluation standards and the restrictions in order to enable competency training on different levels on the same platform.

7.4. Improving Effectiveness Assessment Based on Real Teaching Data

Once teaching data have been collected over several teaching cycles, the effectiveness of the reform should not be judged only by qualitative statements such as "a marked increase in student engagement." Data from at least two teaching cycles can be used to compare the attainment of course objectives, scores on different dimensions of comprehensive projects, the quality of graduation projects, questionnaire results, and evaluations from industry partners, either across different grade levels or before and after the reform. When appropriate, statistical tests can also be used to examine differences between the comparison groups. Research papers or teaching-quality reports should clearly state the sample size, assessment methods, and data sources so that the conclusions about reform effectiveness are better supported.

8. Conclusion

The acquisition of practical skills in the Measurement and Control Technology and Instrumentation major depends not only on a few laboratory courses or final projects, but also requires coverage throughout the whole undergraduate curriculum. According to the advancement of practical skills, this research categorizes the students' abilities into four aspects: basic practical skills, comprehensive professional skills, engineering system skills and innovative practical skills. A progressive and project-based practical teaching framework is established. By organizing the whole process of projects, integrating the evaluation of both the progress and results, and maintaining an improving mechanism, the practical teaching is gradually changed from the training of single skills to the development of system level engineering competence.

In actual use, the proposed system needs to be modified according to the educational position of the institution, the faculty's knowledge, the laboratory facilities and the regional industrial features. The efficiency should be evaluated by means like the achievement of the course objectives, the process data of the projects, the students' comments and the enterprise appraisals obtained from several teaching processes. By means of continuous feedback and adjustment, the practical teaching system can be improved further to establish a unique and applicable model for the development of practical talents.

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